SPECTROSCOPIC DIAGNOSTICS OF DISK ACCRETION IN HERBIG AE/BE STARS

L. GHANDOUR, S. STROM, S. EDWARDS, L. HILLENBRAND
Five College Astronomy Department, Univ. of Mass, Amherst, MA

ABSTRACT High resolution spectra of 30 Herbig Ae/Be stars are examined for evidence of accretion disk activity. Standard photospheric stellar templates are subtracted from the observed Ae/Be spectra. The residual spectra are then used to examine the following accretion diagnostics: (1) the frequency of direct mass inflow signatures as exhibited by inverse P-Cygni line profiles, (2) relations between forbidden line emission and infrared color indices, (3) limits on any optical continuum excess, or spectral "veiling", which, if produced in a hot boundary layer, sets limits on mass accretion rates.

INTRODUCTION

Observational evidence gathered over the past decade indicates that solar-type pre-main sequence stars are surrounded by circumstellar accretion disks at birth. This evidence includes observations of:

- 1. *excess infrared emission* with spectral energy distribution consistent with origin in an optically thick accretion disk;
- 2. *excess optical and ultraviolet continuum emission* arising in either a classical or magnetospheric boundary layer, and with a magnitude proportional to the accretion luminosity inferred from excess infrared emission;
- 3. *forbidden line emission* with strength proportional to both excess infrared and optical/uv emission;
- 4. *kinematic signatures of accretion,* most notably inverse P Cygni (IPC) profiles in the Balmer series and in other strong resonance lines (*e.g.* Na I; Ca II; Mg II).

Several investigators have studied and modeled the spectral energy distributions of Herbig Ae/Be stars, attributing the infrared excess to both accretion disks and envelopes (Hillenbrand *et al.*, 1992; Hartmann, Kenyon and Calvet, 1993; Natta *et al.*, 1993). In this contribution, we present preliminary results using new spectroscopic data to explore whether the last three aforementioned accretion-related phenomena observed for solar-type PMS stars have analogs among their higher mass counterparts, the Herbig Ae/Be stars, by subtracting a standard photospheric template of matching spectral type and *vsini*. This technique separates the stellar photosphere from the observed spectrum, permitting us to better examine the excess emission.

BOUNDARY LAYER EMISSION (VEILING)

For solar-type stars, excess optical continuum emission produced in a boundary layer is correlated with excess infrared emission produced in a circumstellar accretion disk, and can exceed photospheric levels by a factor of $r = 10$, where r is the ratio of the excess continuum emission to photospheric continuum fluxes (Hartigan *et al.*, 1991). However, *Herbig Ae/Be stars show no evidence of excess optical continuum emission* even though the accretion rates predicted from observed infrared excess emission suggest that such optical emission should be detected with relative ease if the boundary layer temperature is comparable to that in solar-type PMS stars, $T_{BL} \sim 10{,}000$ K.

Figure I demonstrates how the subtraction of a standard template quantifies the excess optical continuum emission. In the first 2 panels, the solid line represents the observed high resolution spectrum of AB Aur (A0, $vsini = 85\ km/s$), and the dashed line represents standard spectrum of corresponding spectral type and $vsini$. The difference between the Herbig Ae/Be star and the standard is shown in the third panel, and is zero to within the observational errors. The middle panel shows that the veiling inferred from the excess infrared emission, $r_{pred} = 1.8$, would be detectable, if present. The observational limit on r is set by the rotational broadening of the photospheric features. For our sample, none of the Herbig Ae/Be stars show evidence for veiling.

We conclude that either (1) the Herbig Ae/Be stars differ from solar-type, pre-main sequence stars by having boundary layer temperatures that are either indistiguishable from the stellar photospheres, or are significantly hotter than what is expected from the boundary layer surrounding a lower-mass PMS star, or (2) that the accretion rates derived from excess infrared emission are too high, perhaps because the IR excess include a significant contribution from a more distant "envelope" region (Hartmann and Kenyon, 1993; Natta *et al.*, 1993).

KINEMATIC SIGNATURES OF DISK ACCRETION

Many of solar-type pre-main sequence stars surrounded by circumstellar accretion disks show kinematic evidence of accretion: inverse P-Cygni profiles (Calvet and Hartmann, 1992). Herbig Ae/Be stars also show clear evidence of IPC profiles. Figure II illustrates the effect of subtracting a standard photosphere from the Hβ profile of T Ori, an A2 Herbig Ae star. Of our total sample of 30 Herbig Ae/Be stars, 4 show definitive IPC structure in residual Hβ, and $\sim 25\%$ are suggestive of IPC profiles, with a majority among the late B and A stars.

FORBIDDEN LINE/DISK ACCRETION CORRELATIONS

Another solar-type PMS signature of disk accretion is the propotionality of the strength of forbidden lines to the IR excess and optical continuum emission (Edwards *et al.*, 1989). Our spectra show evidence of similar correlations among the Herbig Ae/Be stars. Figure III shows the correlation between the [O I] and the excess disk emission, represented by the (I - N) color index, which is equivalent to the ratio of the flux at $0.9\mu m$ to the flux at $10.6\mu m$. The stars with higher IR excesses are also those with stronger [O I] emission, implying

FIGURE I An illustration of how optical excess emission for Herbig Ae/Be stars is quantified.

FIGURE II A plot of the observed Hβ profile for the Herbig Ae/Be star T Ori (solid line), along with the Hβ profile for a standard star of identical spectral type (dashed line). The *residual* (object - standard star) Hβ line profile shows clear evidence for a redward-displaced absorption component.

FIGURE III A plot of the equivalent width of the [O I] λ6300Å emission line versus (I - N) for a sample of Herbig Ae/Be stars. Open symbols indicate upper limits. The dashed line signifies the expected (I - N) for an optically thick disk, viewed pole-on.

a common origin, namely an active accretion disk. Note that the stars lacking disks (with low (I - N) values) show no emission, a behavior true of the weak-line T Tauri stars.

CONCLUSIONS

Herbig Ae/Be stars meet three out of the four accretion diagnostics outlined in the Introduction. In this contribution we have investigated the last three points and have found that, even though Herbig Ae/Be stars show no evidence of the excess optical continuum emission anticipated from a boundary layer, they do show kinematic signatures of infall seen in Hβ residual profiles, and they have forbidden line strengths that are proportional to their infrared excesses.

REFERENCES

Calvet, N., and Hartmann, L. 1992, ApJ, **386**, 239.

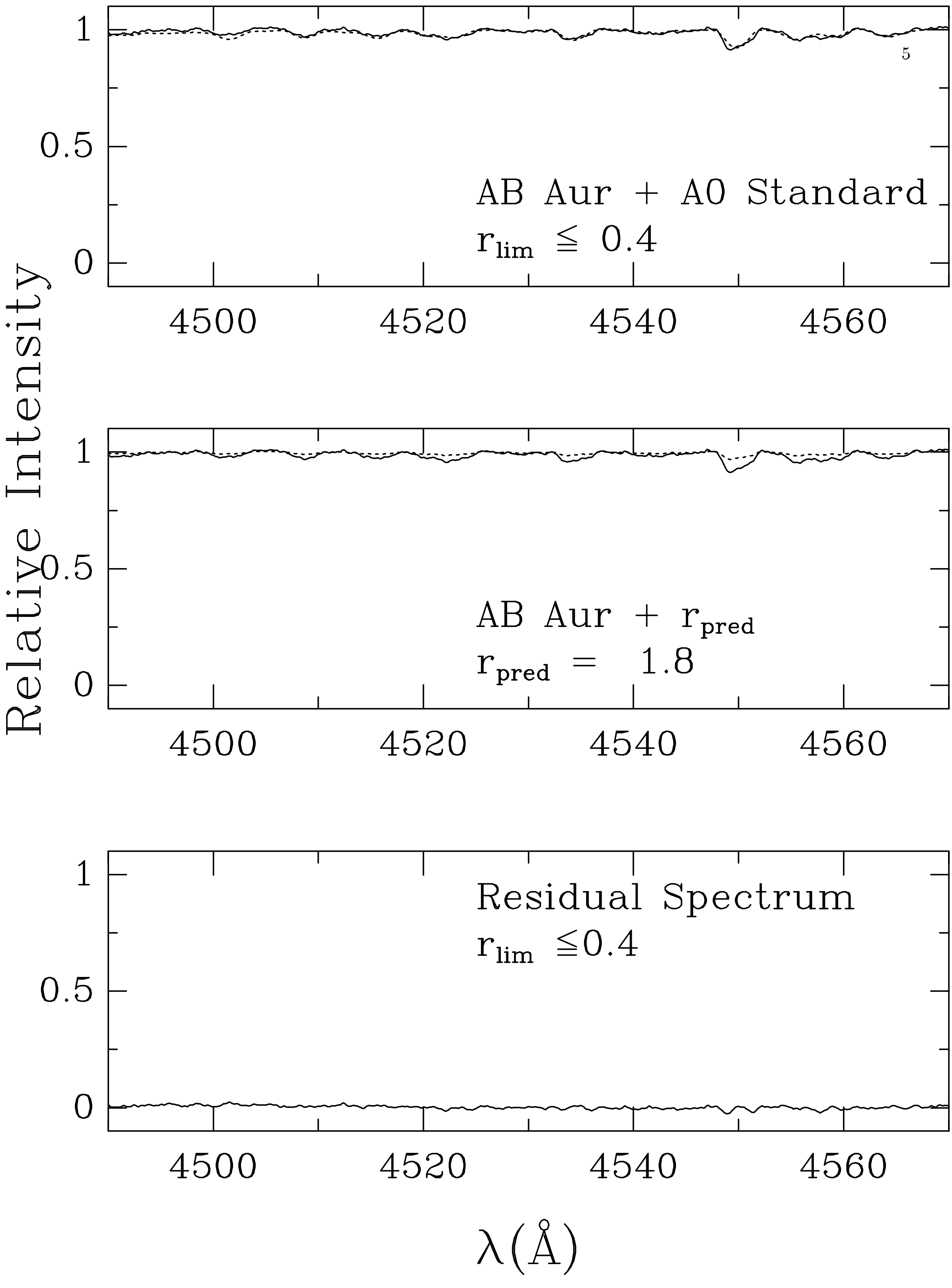
Edwards, S., Cabrit, S., Ghandour, L., and Strom, S. 1989, in *Low Mass Star Formation and Pre-Main Sequence Objects*, ESO Workshop and Proceedings No. 33, ed. B. Reipurth, p. 385.

Hartigan, P., Kenyon, S., Hartmann, L., Strom, S., Edwards, S., Welty, A., and Stauffer, J. 1991, ApJ, **382**, 617.

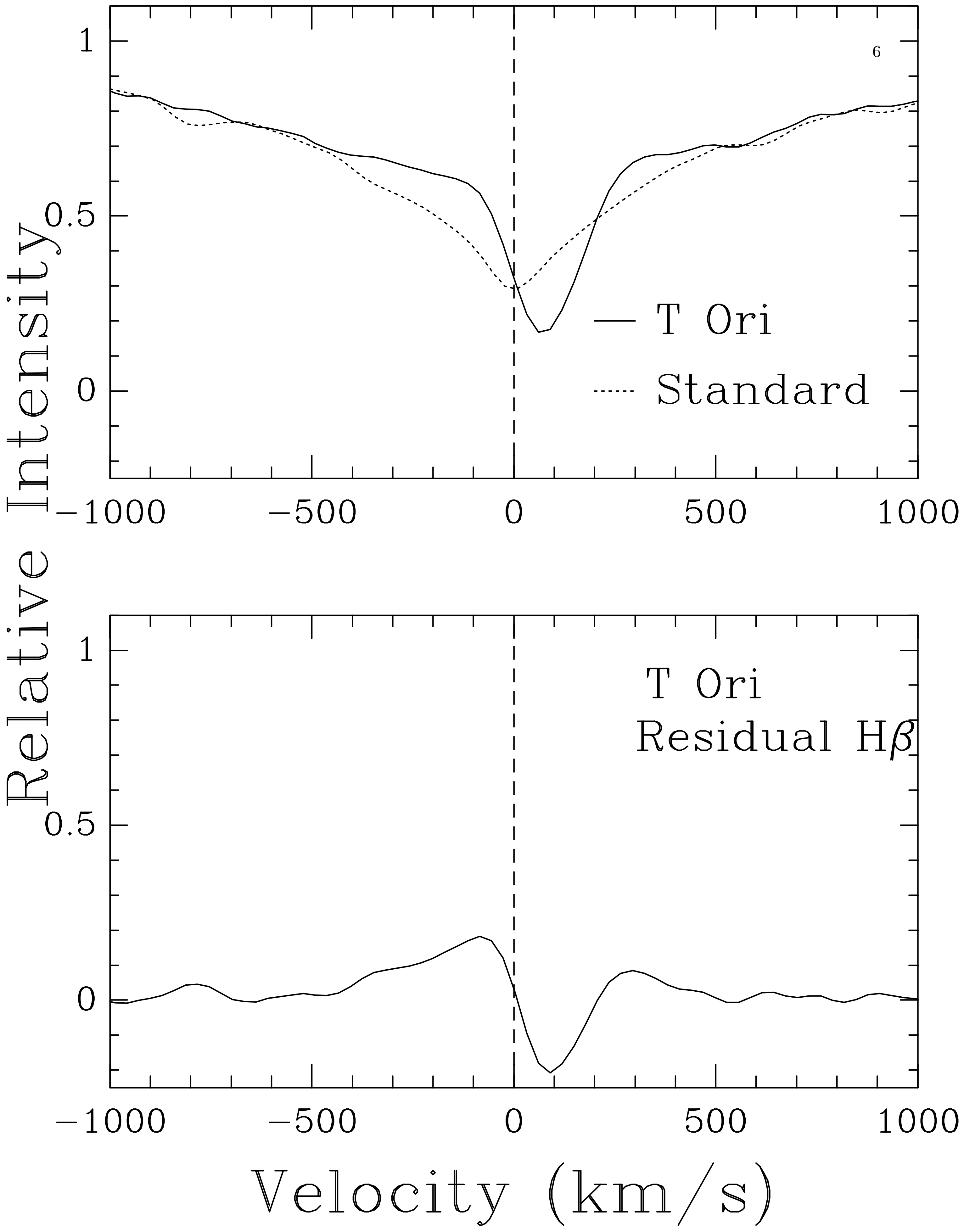
Hartmann, L., Kenyon, S., and Calvet, N. 1993, ApJ, **407**, 219.

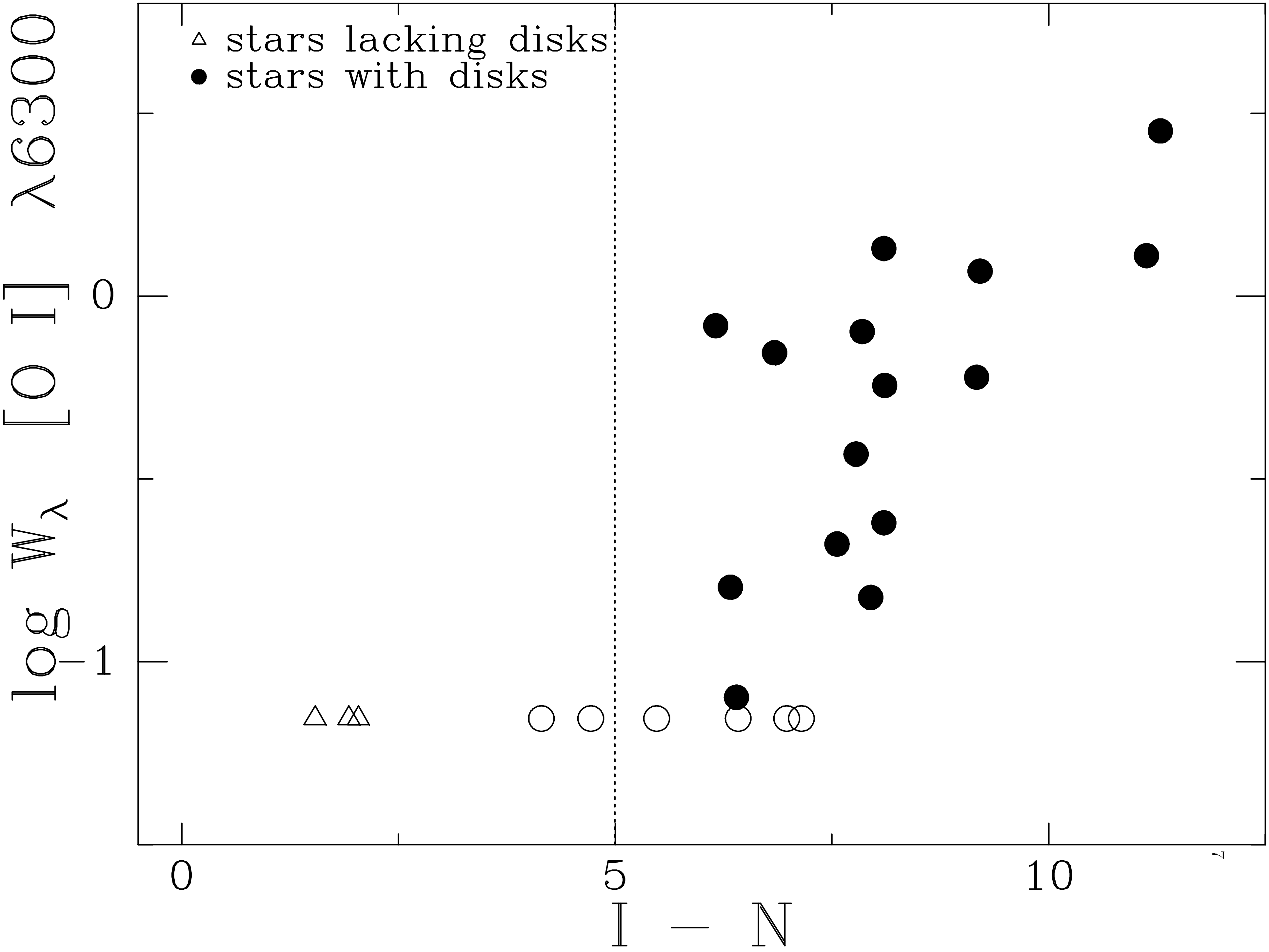
Hillenbrand, L., Strom, S., Vrba, F., and Keene, J. 1992, ApJ, **397**, 613.

Natta A., Palla, F., Butner, H., Evans, N., and Harvey, P. 1993, ApJ, **406**, 674.



AB Aur + A0 Standard
$r_{lim} \leqq 0.4$
AB Aur + r_{pred}
$r_{pred} = 1.8$
Residual Spectrum
$r_{lim} \leqq 0.4$
Relative Intensity
$\lambda(\AA)$
1
0.5
0
4500
4520
4540
4560
5


6
T Ori
Standard
T Ori
Residual Hβ
Relative Intensity
Velocity (km/s)
−1000
−500
0
500
1000
0.5
1


stars lacking disks
stars with disks
log W_λ [O I] λ6300
0
−1
0
5
10
I − N
7